Integrated Nutrient Management Research on Sweet Potato at Hobu, Morobe Province

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Abstract

In order to investigate the effect of organic and inorganic nutrient sources on sweet potato tuber yield, we carried out a series of experiments at Hobu, Morobe Province, PNG. In the first experiment, plots were planted with *Piper aduncum*, *Gliricidia sepium* and *Imperata cylindrica*. After one year, these plants were slashed and sweet potato was planted. Sweet potato yield was lowest in plots with previous gliricidia, but there were no differences in yield between previous piper and imperata. In the second season, there was no significant difference in sweet potato yields between the plots. The second experiment consisted of a factorial fertiliser trial with four levels of nitrogen (0, 50, 100 or 150 kilograms per hectare) and two levels of potassium (0 or 50 kilograms per hectare). Nitrogen fertilisers increased tuber yield in the first season, but depressed tuber yields in the second and third seasons. Nitrogen fertiliser significantly increased vine yields in all three seasons. Potassium fertiliser had no effect on marketable tuber yield, but increased nonmarketable tuber yields. The third experiment compared nitrogen provided by inorganic fertiliser or by poultry litter at four rates (0, 50, 100 or 150 kilograms per hectare). No difference was found between the inorganic fertiliser and poultry litter, and highest yields were found at 100 kilograms of nitrogen per hectare. In the second season, no significant response to nitrogen was observed. This research indicates that sweet potato yield can be significantly increased by either inorganic or organic nitrogen applications, although yield variation is considerable. Sweet potato yields after fallow were moderate but less variable than yields following inorganic nutrient inputs. Fallowing seems the safest way to obtain steady sweet potato yields; with extra inputs through inorganic fertiliser or poultry litter, tuber yields may be strongly increased or decreased.

UNTIL the 1980s, it was widely perceived that inorganic fertilisers were a viable means of increasing land productivity in the low fertility soils of the humid tropics. This line of thought was adopted by, among others, the Food and Agriculture Organization (FAO) Freedom from Hunger Campaign and its Fertiliser Program, which began in the 1960s. Organic fertilisers (e.g. compost or farmyard manure) were regarded as important, but it was obvious that they were not available in sufficient quantity to drastically increase food production. In the early 1980s, various reports showed that the use of inorganic fertilisers in the tropics had stagnated, and this was explained by poor marketing and inadequate profitability. From that time on, integrated nutrient management has been advocated. Essentially, this involves the combination of both inorganic and organic fertilisers to increase crop production (Janssen 1993).

In this paper, we present the results of integrated nutrient management research with sweet potato (*Ipomoea batatas* (L.) Lam.) in the humid lowlands of Morobe Province, PNG. Despite the fact that sweet

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potato is the main staple crop in many parts of PNG, the number of detailed, integrated nutrient management experiments with sweet potato is limited (Hartemink and Bourke 2000). Furthermore, most nutrient management experiments have been conducted on experimental stations and little work has been done in farmers' fields. This is particularly unfortunate since poor crop nutrition contributes to the low yield of root crops of many farmers in PNG and throughout the Pacific region (Halavatau et al. 1998).

The research that we report here took place onfarm at Hobu (6°34'S, 147°02'E), about 15 kilometres north of the PNG University of Technology (Unitech) at Lae, Morobe Province. The experimental site was amongst farmers' fields and all field operations (planting, weeding, harvesting, etc.) were managed by the researchers. The experiments were conducted between November 1996 and December 1998. Three sets of experiments were conducted: (i) a fallow experiment with both natural and improved fallows; (ii) inorganic fertiliser experiments with nitrogen (N) and potassium (K); and, (iii) poultry litter fertiliser experiments. The main aim of these experiments was to assess the effect of different nutrient inputs on sweet potato yield.

Environmental Conditions at Hobu

Hobu is on the foothills of the Saruwaged mountain range in Morobe Province, which forms the major landmass of the Huon Peninsula. The experimental site was located on an uplifted alluvial terrace at an altitude of 405 metres above sea level, with slopes of less than 2%. The soils at this location were derived from a mixture of alluvial and colluvial deposits dominated by sedimentary rocks and coarse- to medium-grained basic igneous rocks. The soils are layered with water-worn gravelly and stony layers below 0.2 metres of depth. Many of the gravels and stones are rotten, and effective rooting depth is over 0.7 metres. The soils are generally fertile with moderately high organic carbon (C) contents and high levels of exchangeable cations. The topsoils are clayey and have bulk densities of 0.6–0.8 kilograms per cubic decimetre (kg/dm^3). Table 1 presents some chemical and physical properties of the soils at Hobu. The soils are classified as mixed, isohyperthermic, Typic Eutropepts (United States Department of Agriculture Soil Taxonomy) or Eutric Cambisols (World Reference Base) (Hartemink et al. 2000b). Inceptisols (Eutropepts) are the most common soils in PNG, covering approximately 40% of the country (Bleeker 1983). In the Hobu area, Sayok and Hartemink (1998) showed that erosion under sweet potato on a 58% slope was less than 4 tonnes per hectare (ha) per year, which is a very low erosion rate. However, since the experiments described in this paper were carried out on land with a slope of less than 2%, erosion was not a problem.

Rainfall records for the experimental site were available only since the start of the experiments in November 1996. In 1997, there was a total rainfall of 1897 millimetres (mm), probably well below the long-term average due to the El Niño southern oscillation climatic event that severely affected the Pacific in 1997–98. In the first six months of 1998, more rain fell than in the whole of 1997. March 1998 was a particularly wet month, with 725 mm of rain. Unitech (Morobe Province) total rainfall in 1997 was only 2594 mm compared with the long-term annual mean of 3789 mm measured over 20 years. Temperature data are not available for the experimental site, but average daily temperatures at Unitech were 26.3°C. Since Unitech is at a lower altitude (65 metres above sea level) than the experimental site, temperatures at Hobu were probably slightly lower.

An area of about 0.5 ha of secondary vegetation was slashed manually at the beginning of November 1996. The vegetation consisted mainly of *Piper aduncum* (L.) and, to a lesser extent, *Homolanthus* sp., *Macaranga* sp., *Trichospermum* sp. and *Trema orientalis* (Rogers and Hartemink 2000). The site had been intensively used for growing food crops, but had been fallow since 1992. All vegetation debris was removed and no burning was done, which is in accordance with the land-clearing practices of local farmers.

Effect of Fallow on Sweet Potato Yield

Shifting cultivation systems, in which cropping periods alternate with short fallow periods, are still widely practised in the humid lowlands of Morobe Province. Very little is known about nutrient cycling in these shifting cultivation systems. In particular, the effect on sweet potato yield of nutrient addition by secondary fallow vegetation is largely unknown.

The secondary fallow vegetation in many parts of the lowlands is dominated by *Piper aduncum* (L.), a shrub indigenous to tropical America (Rogers and Hartemink 2000). It is not known how and when *P. aduncum* arrived in PNG, but it was firstly described in Morobe Province in 1935. Farmers claim that piper arrived in the Hobu area in the early 1970s. In the standard work

Table 1. Chemical and physical properties of Typic Eutropepts soil at the experimental site at Hobu, Morobe Province, PNG.[a]

Sampling depth (m)	pH_w	Organic C (g/kg)	Total N (g/kg)	Available P (mg/kg)	CEC ($mmol_c$/kg)	Exchangeable cations ($mmol_c$/kg)			Base saturation (%)	Particle size fractions (g/kg)			Bulk density (tonnes/m^3 of soil)
						Ca	Mg	K		Clay	Silt	Sand	
0–0.12	6.2	54.6	5.0	9	400	248	78	16.9	86	480	160	360	0.82
0.12–0.23	6.3	25.4	2.3	2	155	220	84	1.9	100	620	110	270	0.85
0.23–0.39	6.6	13.7	1.3	1	338	200	105	1.4	91	600	140	260	0.97
0.39–0.99	7.4	2.1	0.3	4	357	189	99	1.4	82	340	110	550	1.30

CEC = cation exchange capacity (pH 7); $mmol_c$ = millimoles of charge; pH_w = pH in water

[a] Samples taken from a soil pit in February 1997, fallowed since 1992

on New Guinea vegetation by Paijmans (1976), *P. aduncum* is not mentioned as a separate species. Nowadays that is hard to imagine, because in many parts of the humid lowlands piper forms monospecific stands. In Morobe Province it occurs at altitudes of up to 600 metres above sea level, and it is also found in the highlands at altitudes of up to 1900 metres above sea level. It grows very fast, with virtually no undergrowth of weeds or shade-tolerant tree species. Despite this lack of undergrowth, we have never observed signs of severe erosion under piper in PNG.

Farmers in the Hobu area usually have short-term piper fallows (< 2 years) followed by one crop of taro gradually intercropped with sweet potato, sugarcane (*Saccharum* sp.) and banana (*Musa* sp.). The length of the fallow period has, however, recently been reduced due to the need for increased food and cash crop production to accommodate the growing population (Allen et al. 1995; Freyne and McAlpine 1987). In the Hobu area, secondary fallow vegetation is dominated by piper, and imperata grassland is also common.

Although the aggressive invasion of piper has been described, including its possible effect on PNG's rich biodiversity (Kidd 1997; Rogers and Hartemink 2000), there is no information available on the effect of piper fallows on soil and crop productivity. For example, it is not known whether piper fallows are more productive than natural fallows such as imperata. With the shortening of the fallow period, there may be a need to introduce fallow species that improve the soil fertility more rapidly than natural fallows (Young 1997). *Gliricidia sepium* is planted as an improved fallow in some parts of the world, and is one of the most widely cultivated multipurpose tree (Simons and Stewart 1994). Gliricidia is common in the PNG lowlands, where it is used for shade in cocoa plantations.

Experimental design

Sixteen plots each of 6.0 square metres (m^2) were laid out, and four treatments were assigned to the plots in a randomised complete block design. The fallow plots were planted at the end of November 1996. Four plots were planted with piper seedlings (0.4 m) from a nearby roadside. Four plots were planted with gliricidia cuttings (0.4 m) from a local cocoa plantation. Piper and gliricidia fallows were planted at distances of 0.75 m × 0.75 m (17,778 plants per ha). These spacings are often observed in natural piper fallows. In four plots, natural regrowth was allowed to occur, which was immediately dominated by *Imperata cylindrica*. Some minor weeds in the imperata fallow were *Ageratum conyzoides, Sphaerostepanos unitus*, *Rottboellia exalta*, *Sida rhombifolia*, *Polygala paniculata*, *Euphorbia hirta* and *Emilia sonchifolia*. In the remaining four plots, the local cultivar of sweet potato, Hobu1, was planted (E. Guaf, Lowlands Agricultural Experiment Station, Keravat, pers. comm. 1997). This is a widely grown cultivar with red-skinned tubers and white flesh, which appears to be not very susceptible to sweet potato weevil, an important pest in PNG (Bourke 1985b). Planting material was obtained from local gardens and consisted of vine cuttings that were planted almost vertically in the soil using a stick. One cutting of about 0.4 m in length with 4–6 nodes was planted in each hole, a practice which generally gives the highest tuber yield (Levett 1993). Planting distance was 0.75 m × 0.75 m (17,778 plants/ha). The sweet potato plots were continuously cultivated with sweet potato for four seasons and no inorganic fertilisers were applied.

After one year, all fallow vegetation was cut to ground level. Piper plants were separated into stems, branches, leaves and litter. Gliricidia plants were separated into stems, leaves and litter. The imperata fallow produced virtually no litter, so total biomass was taken. In each plot, total fresh matter of the different plant parts was weighed, and samples were taken for dry matter determination and nutrient analysis. Piper and gliricidia stems were removed from the plots; all other plant parts were applied as surface mulch after weighing. The previous fallow plots were then planted with sweet potato like to the continuously cultivated plots. The previous fallow plots were not tilled for planting, and were cultivated with sweet potato for two seasons.

The sweet potato cropping seasons lasted for about 170 days, after which the plots were harvested. Vines were cut at ground level, weighed and removed from the plot. In their gardens, farmers remove vines, a practice that may be related to allelopathic effects that alter nutrient uptake (Walker et al. 1989). Tubers were manually dug, counted, separated into marketable tubers (> 100 grams (g)) and nonmarketable tubers (< 100 g) and removed from the plot. All plots were replanted directly after a harvest. Weeds were pulled out manually and were not removed from the plot. No pesticides were used in the experiments. Figure 1 shows the daily rainfall during the experimental period and during each of the four seasons.

Nutrient input and sweet potato yield

The nutrient input of the one-year fallow is shown in Table 2. Total N returned to the field via gliricidia leaves and litter was 192 kg N/ha compared to

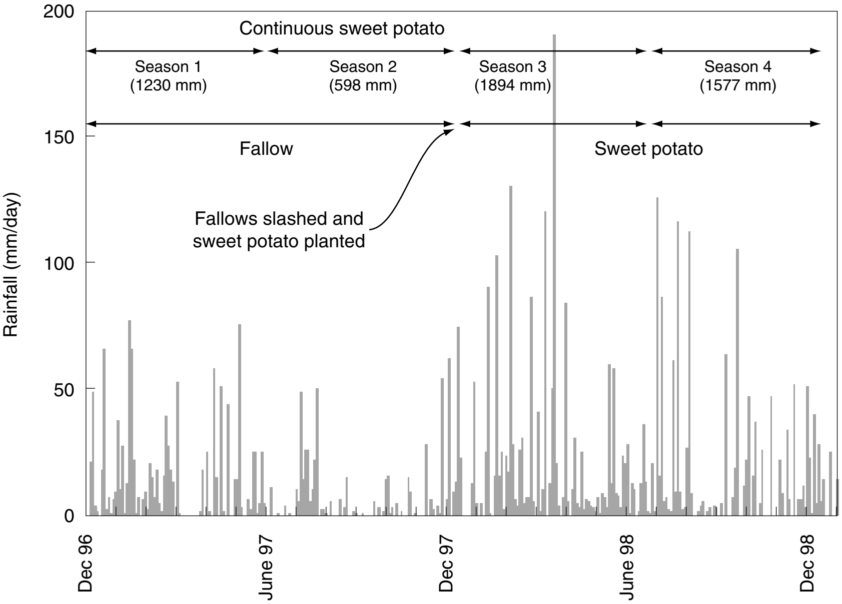

Figure 1. Daily rainfall during fallow trial (total rainfall during each season is given in parentheses).

97 kg N/ha for piper and 76 kg N/ha for imperata. The amount of phosphorus (P) returned by the fallow vegetation was similar for all three fallows at around 12–14 kg/ha. Piper returned 206 kg K/ha compared to 89 kg K/ha returned by gliricidia and imperata.

In the first season after the fallow, marketable sweet potato yield after piper and imperata was about 11 tonnes/ha, which was significantly higher than that under continuous sweet potato (7.8 tonnes/ha) or after gliricidia fallow (8.4 tonnes/ha) (Table 2). Variation in nonmarketable tuber yield after the fallows was large, and differences were not statistically significant. Total tuber yield (marketable plus nonmarketable tubers) was highest after piper (14.4 tonnes/ha) and significantly lower after gliricidia fallow (9.9 tonnes/ha). Vine yield was similar under continuous sweet potato cultivation and after piper and gliricidia fallow, but significantly lower after imperata fallow.

In the second season, there was no fallow effect on marketable sweet potato yield. Nonmarketable tuber yield was significantly lower in plots with previous imperata, but no differences were found between the other treatments. Total tuber yield in the second season was similar for all treatments. Cumulative tuber yield over the two seasons was about 29 tonnes/ha for piper and imperata but less than 25 tonnes/ha in the continuous sweet potato plots. Cumulative vine yield over the two seasons was 53–60 tonnes/ha for continuous sweet potato and plots with previous gliricidia or piper, but it was less than 40 tonnes/ha in plots with previous imperata.

Effect of Inorganic Fertiliser on Sweet Potato Yield

Literature is available on the use of inorganic fertilisers on sweet potato, although the amount of information is limited compared with other staple crops of the tropics such as rice and maize. Sweet potato consumes considerable amounts of K, and the responses to K fertilisers have been generally recorded (de Geus 1973). Sweet potato has a high N requirement, but can give reasonable yields in soils of poor fertility (Hill et al. 1990), which may be partly due to its capacity to fix atmospheric N through association with symbiotic, non-nodulating bacteria. Estimates have shown that as much as 40% of the N uptake of sweet potato may be derived from di-nitrogen (Yoneyama et al. 1998), although cultivar differences are large. A wide range of N fertiliser requirements has been reported for sweet potato (Hill 1984), but much depends on the cultivar, soil type and climatic conditions (O’Sullivan et al. 1997).

Table 2. Sweet potato yield over two seasons following one year of piper, gliricidia or imperata fallows, or continuous cultivation.

Preceding treatment	Nutrient input[a] (kg/ha)			Yield in tonnes/ha (fresh weight)					
	N	P	K	Marketable tubers		Nonmarketable tubers		Vines	
				First season	Second season	First season	Second season	First season	Second season
Piper	97	14	209	11.2	13.4	3.1	2.1	30.4	22.9
Gliricidia	192	12	89	8.4	14.3	1.6	1.8	31.6	26.1
Imperata	76	12	89	11.3	15.2	1.5	1.1	20.7	18.9
Continuous sweet potato[b]	0	0	0	7.8	12.8	2.4	2.0	32.3	27.4
SED[c]				1.3	ns	ns	0.3	3.9	4.1

ns = not significant ($P > 0.05$)

[a] Nutrients returned with the aboveground biomass when the fallows were slashed and the first season of sweet potato was planted.

[b] Yields from the third and fourth season under continuous cultivation

[c] Standard error of the difference in means (SED), with 9 degrees of freedom

In PNG, various inorganic fertiliser experiments have been conducted since the 1950s. Bourke (1977) summarised 17 field trials and 6 pot trials conducted on volcanic ash soils in Keravat, and concluded that N and K were most important. Nitrogen increased vine yield, but N responses to tuber yield were inconsistent. Potassium fertiliser had no effect on vine yield, but K increased tuber yield and the number of tubers. Somewhat similar findings have been reported by Hartemink et al. (2000a) working on alluvial soils near Lae. Floyd et al. (1988), also working on volcanic ash soils, showed that P and K applied as organic manure gave better responses than inorganic fertilisers. Overall, the literature seems to suggest that sweet potato in PNG responds inconsistently to inorganic fertilisers.

Experimental design

The inorganic fertiliser experiment at Hobu was laid out as a randomised block design with four levels of N (0, 50, 100 or 150 kg/ha) and two levels of K (0 or 50 kg/ha) in a factorial combination. Each treatment was replicated four times and plot size was 4.5 m × 4.5 m. The experiment lasted for three consecutive seasons between February 1997 and August 1998. Throughout this experiment the sweet potato cultivar Hobu1 was used. During the experiment, weeds were pulled out manually and were not removed from the plot. No pesticides were used.

The first crop was planted on 10 February 1997. Potassium was broadcast directly after planting. Nitrogen fertiliser was given in split applications. The 100 kg/ha treatment received 50 kg N/ha at planting and 50 kg N/ha 59 days after planting (DAP). The 150 kg/ha group received 50 kg N/ha at planting, 50 kg N/ha at 59 DAP and a further 50 kg N/ha at 80 DAP. The first crop was harvested on 30 July 1997 (170 DAP). At harvest, vines were cut at ground level, weighed, and removed from the plot. Tubers were manually dug, counted and separated into marketable tubers (> 100 g) and nonmarketable tubers (< 100 g), then removed from the plot. Total rainfall received during the first crop was 1028 mm. All plots were replanted directly after the harvest.

The second crop was planted on 1 August 1997. Potassium and the first application of N fertiliser were given on 8 August 1997. The second N application was given on 30 September 1997 (60 DAP) and the third on 21 October 1997 (81 DAP). Plots were harvested on 10 February 1998 (193 DAP) using harvesting procedures similar to the first season. Rainfall in the second season was 1034 millimetres (mm).

The third crop was planted on 12 February 1998. Potassium and the first N application were given on 20 February 1998. The second and third N applications were given on 10 April 1998 (57 DAP) and 6 May 1998 (83 DAP), respectively. Harvesting took place on 6 August 1998. Total rainfall received in the third season was 2214 mm. Figure 2 shows the daily rainfall during the experimental period and for each of the three seasons.

Sweet potato yield

Sweet potato tuber and vine yields from each of the three seasons are shown in Table 3. Marketable tuber yield in the first season ranged from 18.3 to 23.8 tonnes/ha but was not affected by K fertiliser. Marketable tuber yields were increased by N application ($P = 0.10$), with the highest yield being obtained with 100 kg N/ha. Nonmarketable tubers were significantly increased by about 1 tonne/ha due to the K fertiliser. Nitrogen fertiliser significantly ($P < 0.05$) increased total tuber yield (marketable + nonmarketable tubers) and also increased vine yield by about 10 tonnes/ha.

In the second season, N fertiliser significantly reduced marketable tuber yields. This reduction was almost linear, from about 25 tonnes/ha with no fertiliser to 17 tonnes/ha with 150 kg N/ha. Potassium fertiliser had no significant effect on the marketable tuber yield but increased nonmarketable tuber yield similarly to the first season. Both N and K fertilisers did not affect total tuber yield but increased vine yields similarly to the first season.

In the third season, yield levels dropped dramatically in all treatments. Marketable tuber yield in the control plots was only 7 tonnes/ha and N fertiliser reduced yield significantly by about 3 tonnes/ha. Nitrogen fertiliser also depressed nonmarketable yield. Vine yield in the control plots was 11 tonnes/ha lower than in the second season. Nitrogen fertiliser significantly increased vine yield to about 12 tonnes/ha at 100 kg N/ha.

The overall pattern emerging from these trials is an increase in yield in the first season with N fertilisers but a decrease in tuber yields in the second and third seasons (Table 4). Nitrogen fertiliser significantly increased vine yield in all three seasons. Potassium fertiliser had no effect on marketable tuber yield but increased nonmarketable tuber yield.

Effect of Poultry Litter or Inorganic Fertiliser on Sweet Potato Yield

In PNG, various field trials with sweet potato have shown that organic fertilisers give higher and more consistent yields than inorganic inputs (D'Souza and

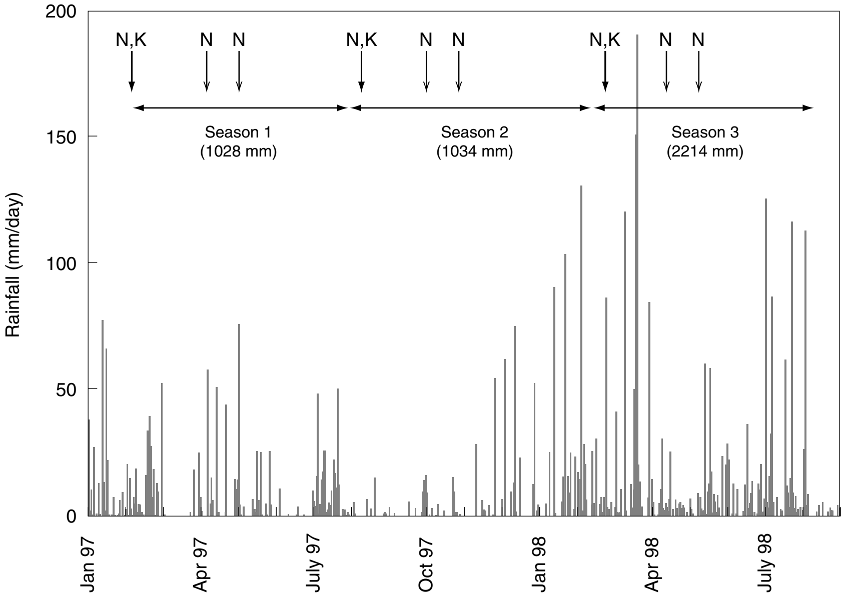

Figure 2. Daily rainfall during inorganic fertiliser trial (total rainfall during each season is given in parentheses). Vertical arrows indicate timing of nitrogen (N) and potassium (K) fertiliser applications.

Bourke 1986; Floyd et al. 1988; Preston 1990). Various factors could be involved, such as the addition of beneficial nutrients in organic matter that are not found in inorganic fertilisers, and the improvement of physical or biological properties of the soil.

In the highlands of PNG, compost and coffee pulp are available as organic nutrient sources for sweet potato. In the lowlands of Morobe Province, poultry litter is widely available because of the many smallholders who raise chickens for large commercial companies such as Zenag and Tablebirds. The chickens are usually raised in sheds on sawdust, with feed provided by the companies. The poultry litter (manure and sawdust) is usually removed from the shed when the chickens are slaughtered, and it is dumped near the shed. It is hardly used in food gardens despite the fact that it contains many nutrients.

Igua (1985) conducted an experiment near Port Moresby with poultry litter as fertiliser for sweet potato, and found that highest yields were obtained with 10 tonnes of poultry litter/ha. Higher application rates depressed sweet potato yield. No other reports are available on the effect of poultry litter on sweet potato yield in PNG.

Experimental design

Our poultry litter experiment consisted of four levels of N (0, 50, 100 or 150 kg/ha) given as poultry litter or as inorganic fertiliser (NPK). The same

Table 3. The effect of nitrogen and potassium fertilisers on sweet potato yield over three seasons.

Inorganic fertiliser (kg/ha)[a]		Yield in tonnes/ha (fresh weight)								
N	K	Marketable tubers			Nonmarketable tubers			Vines		
		First season	Second season	Third season	First season	Second season	Third season	First season	Second season	Third season
0	0	18.3	24.6	7.0	3.2	1.0	1.3	39.9	37.3	26.4
50	0	22.7	20.4	5.2	3.2	1.2	0.9	49.1	46.6	30.4
100	0	23.8	21.5	5.8	3.3	1.1	1.5	52.9	51.0	39.9
150	0	23.2	17.3	2.9	4.0	1.1	0.5	53.0	47.5	36.9
0	50	17.7	21.7	5.6	3.3	1.7	1.8	51.5	49.4	30.9
50	50	21.2	17.9	2.6	4.5	1.7	0.9	49.1	45.5	32.9
100	50	23.5	20.4	6.0	5.4	1.4	1.9	57.5	61.7	36.6
150	50	19.6	17.8	2.7	4.5	1.9	0.7	55.7	53.1	35.5
SED[b]		4.3	3.6	1.5	0.9	0.5	0.4	5.3	6.2	3.1

[a] Applied during each season

[b] Standard error of the difference between two means (SED), with 21 degrees of freedom

Table 4. Summary of the effects of inorganic nitrogen and potassium fertilisers on sweet potato yield over three seasons.

	Nitrogen			Potassium		
	First season	Second season	Third season	First season	Second season	Third season
Marketable tuber yield	+	–	–	0	0	0
Nonmarketable tuber yield	0	0	–	+	+	0
Total tuber yield	+	0	–	0	0	0
Vine	+	+	+	0	+	0

0 = no effect; + = yield-increasing effect; – = yield-depressing effect

amount of K and P as was given to the poultry litter plots was applied to the inorganic fertiliser plots. The experiment was laid out as a randomised complete block design with four replicates per treatment. The experiment lasted for two seasons. The first crop was planted on 8 August 1997 and, directly after planting, the poultry litter or NPK fertiliser was applied. The NPK fertiliser (ammonium sulfate) application was split, and the second application was given on 18 November 1997 (108 DAP). All plots were harvested on 24 February 1998 (200 DAP). The second crop was planted on 4 March 1998 and poultry litter or NPK fertiliser was applied directly after planting. The second NPK application was given on 29 May 1998 (86 DAP). The crops were harvested on 10 September 1998 (190 DAP). Harvesting techniques were similar to those used in the fallow and inorganic fertiliser experiments. Figure 3 shows the daily rainfall during the experiment for the two seasons: 1203 mm and 2091 mm in the first and second seasons, respectively.

Nutrient concentrations of the poultry litter in the first season were 24.6 g N/kg, 15.7 g P/kg, 22.5 g K/kg, 30.2 g calcium (Ca)/kg, and 6.4 g magnesium (Mg)/kg. The poultry litter contained about 84% dry matter and 362 g Ca/kg. Application of 50 kg N/ha corresponded to 2.4 tonnes/ha of fresh poultry litter. In the second season, the poultry litter contained lower levels of nutrients: 13.0 g N/kg, 12.5 g P/kg, 10.3 g K/kg, 30.2 g Ca/kg, and 6.4 g Mg/kg. Dry matter content was 59% and application of 50 kg N/ha corresponded to 6.5 tonnes/ha of fresh poultry litter.

Sweet potato yield

In the first season, both poultry litter and inorganic N fertiliser significantly increased marketable sweet potato yield (Table 5). The yield pattern was similar for both N sources (a quadratic response) and highest yields were recorded when 100 kg N/ha was applied. There was no effect on nonmarketable tuber yield in the first season, although inorganic N fertiliser at 150 kg/ha significantly increased vine biomass.

In the second season, both poultry litter and inorganic N fertiliser significantly reduced marketable tuber yield. In the control plots, marketable tuber yield was similar to that of the first season but nonmarketable tuber yield was about 10-fold higher. No effect of poultry litter or inorganic fertiliser was recorded in the second season. Vine yield was, on average, lower in the second season in most treatments. Application of 150 kg N/ha as inorganic fertiliser significantly increased the vine biomass to 51 tonnes/ha.

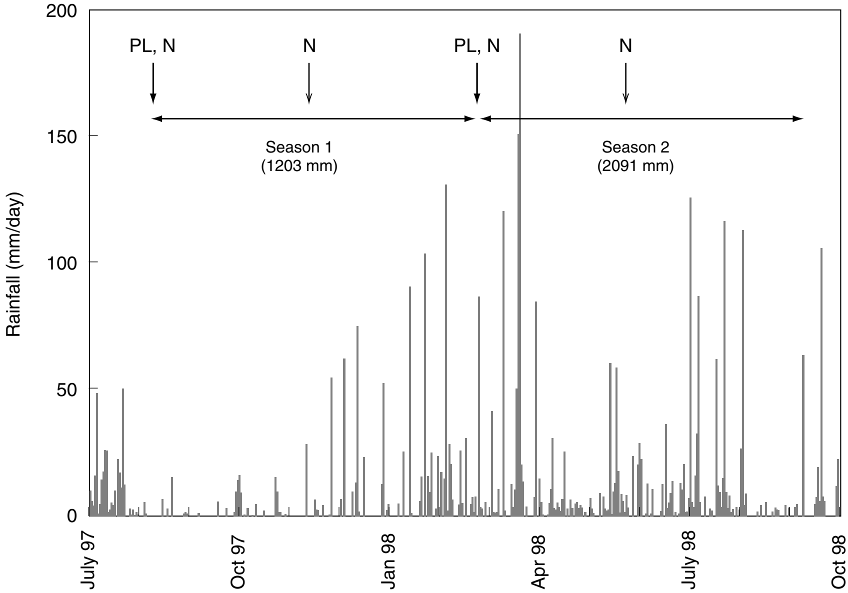

Figure 3. Daily rainfall during poultry litter and inorganic fertiliser trial (total rainfall during each season is given in parentheses). Vertical arrows indicate timing of poultry litter (PL) and inorganic nitrogen (N) fertiliser applications.

Table 5. The effect of inorganic fertiliser or poultry litter on sweet potato yield over two seasons.

N as poultry litter (kg/ha)	N as inorganic fertiliser (kg/ha)	Yield in tonnes/ha (fresh weight)					
		Marketable tubers		Nonmarketable tubers		Vines	
		First season	Second season	First season	Second season	First season	Second season
0	0	12.7	13.3	0.4	4.5	37.1	32.4
50	0	15.7	11.5	0.5	3.1	41.0	34.3
100	0	21.9	7.3	0.8	4.1	48.0	36.4
150	0	13.5	7.4	0.4	4.7	41.1	51.6
SED[a]		4.1	2.7	0.2	1.1	6.2	3.4
0	0	12.7	13.3	0.4	4.5	37.1	32.4
0	50	19.6	6.8	0.6	4.3	37.6	31.0
0	100	26.7	10.6	0.7	5.1	38.1	39.7
0	150	16.6	8.3	0.6	4.3	48.0	42.2
SED[a]		3.6	2.9	0.2	0.8	2.8	6.0

[a]Standard error of the difference in means (SED), with 9 degrees of freedom

Yield Variation and Yield Trends

Considerable yield variation was noticed in all experiments, as is generally found in field experiments with sweet potato (Hartemink et al. 2000b; Martin et al. 1988). Several factors may have contributed to this variation, including rainfall, soil changes and the build-up of pests and diseases.

Yields were generally higher in seasons with lower rainfall. Sweet potato is reportedly very sensitive to excess soil water during the first 20 DAP when tubers are formed (Hahn and Hozyo 1984). We therefore calculated a regression analysis between marketable yield and rainfall over the first 20 DAP (analysis not shown), but found no obvious relationship. We then calculated correlation coefficients for tuber yield, vine yield and total rainfall received in the season (Table 6), which showed that high rainfall at Hobu was significantly correlated with lower marketable and nonmarketable tuber yields. Vine yield was positively correlated with rainfall, suggesting that the reduction in tuber yield in wetter seasons favours the growth of the vine biomass. The number of cropping seasons at Hobu was significantly correlated with both marketable and nonmarketable tuber yield, but not with vine biomass.

At Unitech, the correlations between yield, rainfall and cropping seasons were weaker. The number of cropping seasons did not correlate with tuber yield, but marketable yield was negatively correlated with rainfall during the cropping season.

Changes in soil chemical properties as a result of continuous sweet potato cultivation may be a factor explaining the variation in yield. Table 7 shows soil chemical properties before the first planting and after four seasons (about 2 years) of continuous sweet potato cultivation. The topsoil pH had decreased by 0.4 units, accompanied by a decrease in base saturation. Bulk density was not altered in soils under continuous sweet potato cultivation. This is as expected, since harvesting sweet potato involves digging topsoil with a fork to about 0.2 m depth. No obvious pattern of decline was found in leaf nutrient concentrations, with the highest concentration of all major nutrients found in the first cropping season at Hobu (Hartemink et al. 2000b). A decrease in leaf nutrient concentration was expected because large amounts of nutrient are removed with the sweet potato harvest: in particular, considerable amounts of K are removed with the tubers and vines. At Hobu, about 16 kg N, 7 kg P and 51 kg K were found to be removed with each 10 tonnes/ha of fresh marketable sweet potato tubers (Hartemink et al. 2000b).

In the fallow and inorganic fertiliser experiments, Mr M. Maino and Dr K.S. Powell (University of Technology) made observations on nematodes and sweet potato weevil, respectively. Nematode counts in soil extracts from the fallow experiment showed that the juvenile population of *Meloidogyne* sp. increased with the number of cropping seasons (Hartemink et al. 2000b). The increase in number of nematodes was significant between the first and second seasons but numbers did not differ significantly between the third and fourth seasons. Although the species of *Meloidogyne* could not be identified with certainty, common root-knot species under sweet potato in PNG are *Meloidogyne incognita* and *Meloidogyne javanica* (Bridge and Page 1984).

In the fallow experiment, the above-ground population of weevils at harvest was very low for both seasons, but a considerable proportion of the marketable tubers and vines were damaged. Damaged tubers over both seasons were predominantly categorised in category 1 (only superficial damage to the periderm) (Sutherland 1986). The high level of vine damage was not reflected by tuber damage.

Discussion

Piper fallows resulted in higher sweet potato yields than gliricidia fallows, so there is no obvious advantage of using an improved N-fixing fallow species such as gliricidia. The low yield response after gliricidia fallow is puzzling; it is possible that yields may have been affected by allelopathic compounds in gliricidia. Reports from India have shown that applications of 4–12 tonnes of gliricidia leaf mulch/ha effectively controlled weeds, and that mulching improved total yield of sorghum (Ramakoorthy and Paliwal 1993). The control of weeds was attributed to certain phenolic compounds in the gliricidia mulch. Alan and Barrantes (1998) showed that extracts from gliricidia leaves drastically reduced the germination of certain weed species, including *Ipomoea* sp., in Costa Rica. It is hard to estimate whether the variation in sweet potato yield in our

Table 6. Correlation between rainfall, number of cropping seasons, sweet potato tuber yield and vine yield.

Site	Variable	Marketable yield	Nonmarketable yield	Vine yield
Hobu	Rainfall during the growing season[a]	-0.601^{**}	-0.814^{***}	$+0.866^{***}$
	Number of cropping seasons[b]	-0.556^{*}	-0.622^{**}	+ 0.274
PNG University of Technology	Rainfall during the growing season[a]	-0.558^{**}	+ 0.085	– 0.167
	Number of cropping seasons[b]	– 0.202	+ 0.018	-0.628^{**}

[a]Covariate = number of cropping seasons (i.e. 4 at Hobu and 5 at the PNG University of Technology)
[b]Covariate = rainfall received in the season
*** $P < 0.001$; ** $P < 0.01$; * $P < 0.05$
Source: Hartemink et al. (2000b)

Table 7. Changes in soil chemical properties under continuous sweet potato cultivation (at a sampling depth of 0–0.15 m).[a]

Sampling time	pH_w	C (g/kg)	N (g/kg)	P (mg/kg)	Cation exchange capacity pH 7 ($mmol_c$/kg)	Exchangeable cations ($mmol_c$/kg)			Base saturation (%)
						Ca	Mg	K	
Before planting	6.2	69.9	6.0	10	405	268	61	12.2	84
After four seasons	5.8	71.3	5.9	6	466	227	59	8.4	63
Difference	$P < 0.01$	ns	ns	ns	$P < 0.01$	ns	ns	ns	$P < 0.001$

$mmol_c$ = millimoles of charge; ns = not significant; pH_w = pH in water
[a]Data from fallow experiment; values are the arithmetic mean of four plots
Source: Hartemink et al. (2000b)

experiment was due to allelopathic effects, although the polyphenolic content of the gliricidia leaves was indeed much higher than that of piper or imperata (Hartemink and O'Sullivan, in press).

The gliricidia fallow produced three times more wood than the piper fallows, which is advantageous in the lowland areas where firewood is scarce. The greater biomass of gliricidia may be because gliricidia is better at scavenging the limited nutrients than piper is. It is likely that piper suffered from too little water due to the El Niño drought (Fig. 1): piper grows faster in wetter periods (Hartemink, in press). Piper significantly reduced soil moisture, which is of advantage in wet seasons: Hartemink et al. (2000b) have shown that sweet potato yields were significantly reduced in wetter seasons regardless of the cropping history of the soil (see also Table 7).

Sweet potato tuber yields after imperata fallow were comparable to those after the woody fallows of piper or gliricidia. However, imperata biomass returned less N to the soil, and vine biomass was lower due to the slow decomposition of the biomass and N immobilisation (Hartemink and O'Sullivan, in press). The reduced vine yield after imperata fallow did not result in higher tuber yield, although vine and tuber yields are often inversely related (Enyi 1977). Similarly, a significant yield reduction of sweet potato was observed following the application of more than 10 tonnes/ha of imperata mulch (Kamara and Lahai 1997). The yield reduction was attributed to the low C:N ratio of the mulch, resulting in poor mineralisation and immobilisation of N. Furthermore, it has been suggested that imperata biomass has phytotoxic properties (Kamara and Lahai 1997).

Table 8. The 10 highest and 10 lowest marketable sweet potato yields observed in all nutrient management trials at Hobu.

	Yield (tonnes/ha)	Experiment	Treatment[a]	Season	Rainfall during season (mm)
Highest yield	26.7	Poultry litter	100 kg N/ha (as inorganic fertiliser)	First	1203
	24.7	Inorganic fertiliser	Unfertilised	Second	1034
	23.8	Inorganic fertiliser	100 kg N/ha; no K	First	1028
	23.5	Inorganic fertiliser	100 kg N/ha; 50 kg K/ha	First	1028
	23.3	Inorganic fertiliser	150 kg N/ha; no K	First	1028
	22.7	Inorganic fertiliser	50 kg N/ha; no K	First	1028
	21.9	Poultry litter	100 kg N/ha (as poultry litter)	First	1203
	21.7	Inorganic fertiliser	No N; 50 kg K/ha	Second	1034
	21.5	Inorganic fertiliser	100 kg N/ha; no K	Second	1034
	21.3	Inorganic fertiliser	50 kg N/ha; 50 kg K/ha	First	1028
Lowest yield	2.6	Inorganic fertiliser	150 kg N/ha; no K	Third	2214
	2.7	Inorganic fertiliser	150 kg N/ha; 50 kg K/ha	Third	2214
	2.9	Inorganic fertiliser	50 kg N/ha; 50 kg K/ha	Third	2214
	5.2	Inorganic fertiliser	50 kg N/ha; no K	Third	2214
	5.6	Inorganic fertiliser	100 kg N/ha; 50 kg K/ha	Third	2214
	5.8	Inorganic fertiliser	100 kg N/ha; no K	Third	2214
	6.0	Inorganic fertiliser	No N; 50 kg K/ha	Third	2214
	6.8	Poultry litter	50 kg N/ha (as poultry litter)	Second	2091
	6.9	Inorganic fertiliser	Unfertilised	Third	2214
	7.3	Poultry litter	100 kg N/ha (as inorganic fertiliser)	Second	2091

N = nitrogen; K = potassium

[a] Note that in the poultry litter experiment, the source of N was either inorganic fertiliser or poultry litter; in the inorganic fertiliser experiment, the source of N was only inorganic fertiliser.

In our experiments, short-term fallows of piper and imperata gave slightly higher sweet potato yields than fallows of gliricidia did. From a nutrient perspective, gliricidia fallows are probably more effective, but additional research into nutrient budgets is required before a final assessment can be made of the sustainability of short-term fallows.

The inorganic fertiliser and poultry litter experiments have shown that sweet potato responded to N fertiliser, which confirms other research in PNG (Bourke 1985a; Bourke 1985b; O'Sullivan et al. 1997). The highest yields were obtained with application of 100 kg N/ha, although the response was mostly found in the first season after the fallow, and subsequent seasons gave inconsistent results. However, the response to nutrient inputs was greatly affected by other factors such as rainfall, number of cropping seasons, pests and diseases (Hartemink et al. 2000a; Hartemink et al. 2000b).

Now the question arises as to what is the best treatment to sustain and improve sweet potato yield in the Hobu area. Table 8 shows the 10 highest and lowest yields from all of the experiments. These are average yields for each treatment—variation between plots was large. Some plots had very high marketable tuber yields (up to 39 tonnes/ha), while others had marketable tuber yields of below 20 tonnes/ha. Table 8 clearly shows that most of the highest yields were found in the first and second seasons after the fallow, and when seasonal rainfall was 1000–1200 mm. The lowest yields were recorded in the third season after the fallow, when the seasonal rainfall exceeded 2000 mm. Most importantly, Table 8 shows that none of the fallow treatments were associated with either the highest or the lowest yield rankings. Thus, using fallows appears to be the safest way to obtain steady sweet potato yields. Extra inputs through inorganic fertiliser or poultry litter may either strongly increase or decrease yields.

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